Effects of Stability Control on the Rollover Propensity of Two Sport Utility Vehicles

A Preliminary Investigation

(This presentation was previously presented at the 2001 SAE Government/Industry Meeting)

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Stability Control Background

- Affects vehicle response
  - Throttle (engine) intervention
  - Selective brake application
- First available on high-end luxury passenger cars
- Nineteen automakers now offer stability control
- Presently available on some SUVs
  - BMW X5
  - Mercedes M-Class
  - Toyota/Lexus
    - RX300
    - 4Runner
    - Sequoia
    - Land Cruiser/LX470

NHTSA Research

Desired Test Matrix

- **Must be extensive**
- **Severe Maneuvers**
  - Rollover propensity
    - J-Turn
    - Fishhook
    - Resonant Steer
  - Handling
    - Double Lane Change
    - Elk Test
- **Roadway Orientation**
  - Straight
  - Corners
- **Surfaces**
  - High-mu
  - Lo-mu
  - Transitions
- **Driver Inputs**
  - Throttle
    - With / without
  - Brake Application
    - With / without

Abbreviated Test Matrix

- Brief testing opportunity before and during equipment procurement phase of TREAD Act preparation
- Allowed 3 Phase II maneuvers to be performed with 2 vehicles
- No handling or braking maneuvers

Test Vehicles

- **1999 Mercedes ML320**
  - First production SUV equipped with standard stability control
  - Continental Teves ESP
  - Push-button deactivation
- **2000 Lexus LX470**
  - Large SUV (6000 lbs with outriggers)
  - Aisen VSC
  - Driver cannot disable

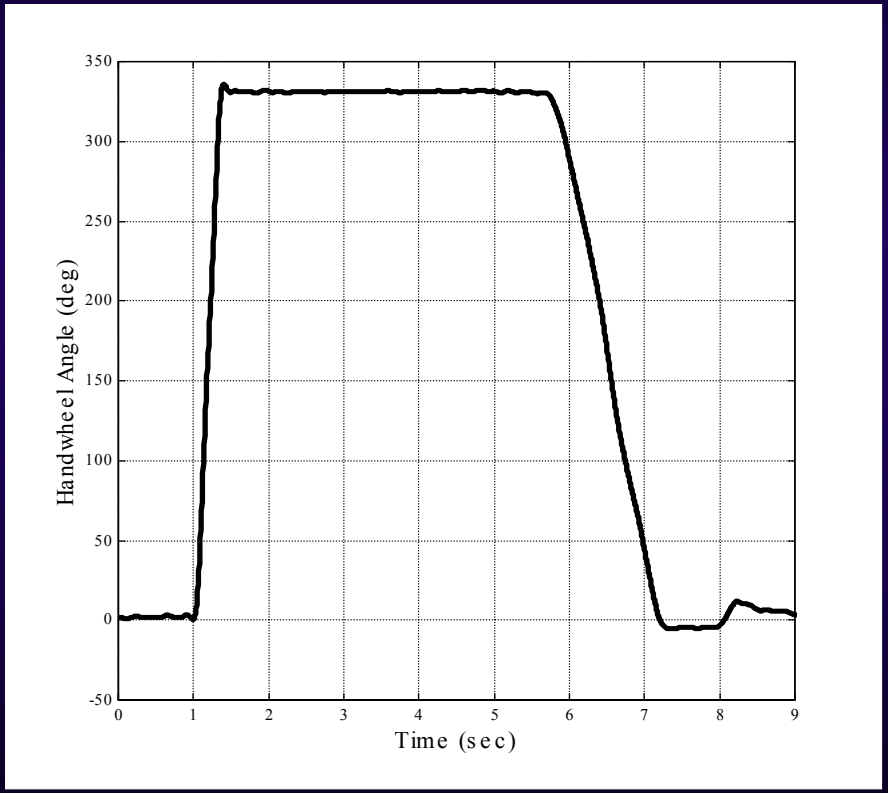
Objective: Investigate how stability control can affect rollover propensity

Test Matrix

- **Phase II Maneuvers**
  - J-Turn (no pulse braking)
  - Fishhook #1
  - Fishhook #2
- **Closed-loop double lane change**

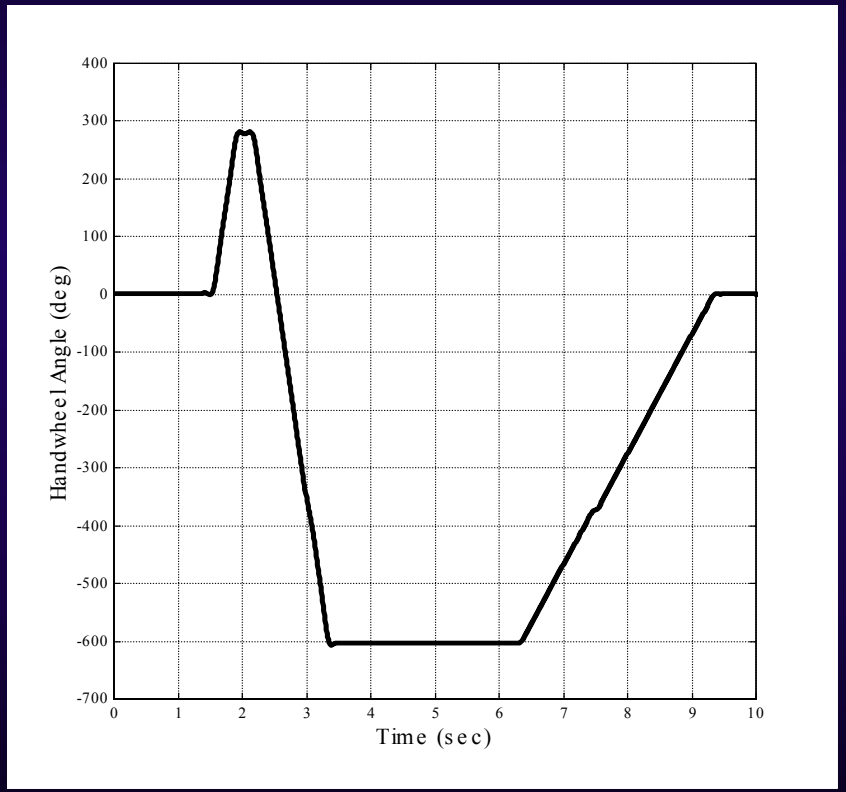
J-Turn

- Identical handwheel inputs for each vehicle
- 330 degree magnitude
- 1000 deg/sec rate



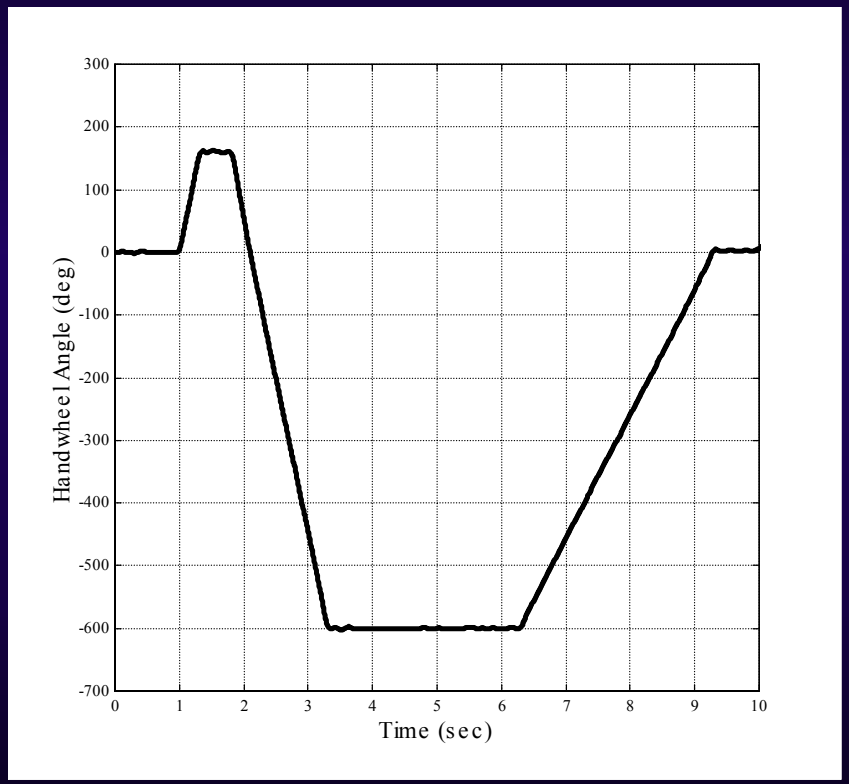
Fishhook #1

- 270 → 600 degree magnitudes
- ML320
  - 0.8 Hz roll natural frequency peak produced with pulse steer
  - 1440 and 750 deg/sec rates
- LX470
  - Response flat in pulse steer
  - Roll natural frequency assumed to be 0.5 Hz
  - 720 and 750 deg/sec rates



Fishhook #2

- Initial steer magnitude based on steering ratio
- ML320
  - Steering ratio = 19.4
  - Initial steer = 146 degrees
- LX470
  - Steering ratio = 21.5
  - Initial steer = 161 degrees
- Reversal = 600 degrees
- All rates = 500 deg/sec

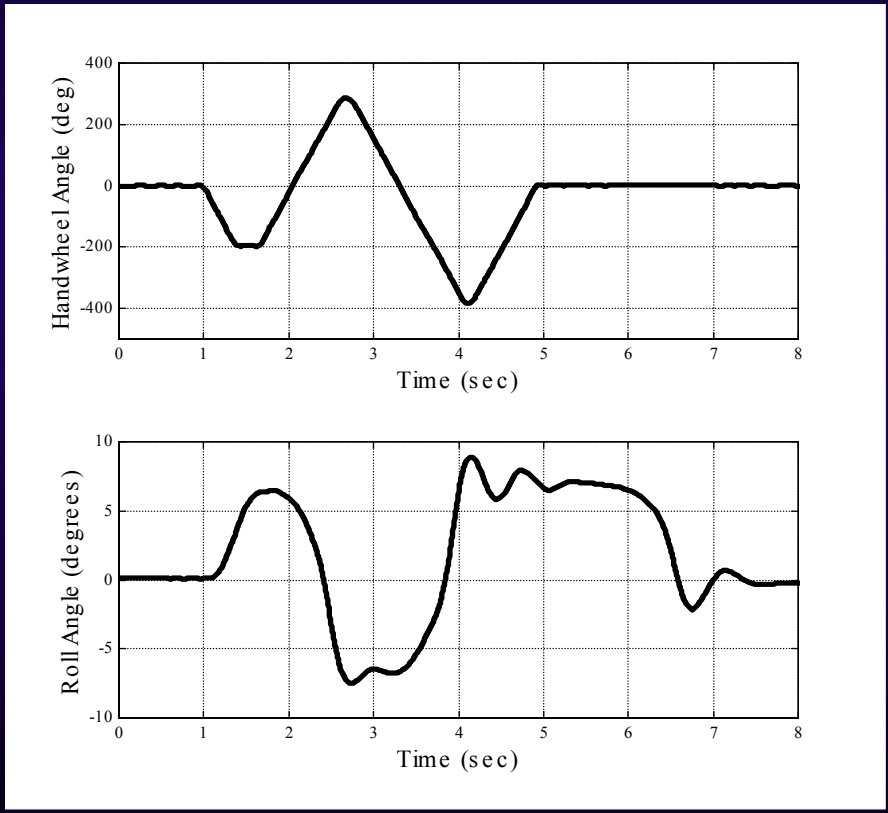


Closed-Loop Double Lane Change

- New maneuver
- Uses roll rate feedback
- Progressively Increasing Steer Maneuver (PRISM)
  - Designed to simulate a driver who over-corrects steering
  - Yaw magnitude increases with each successive handwheel input
- Performed with the LX470

Closed-Loop Double Lane Change

- Handwheel magnitudes based on Steering Gain #1 test
- Sample Steering Magnitudes
  - LX470
  - 36.8 mph
  - Initial steer = θ_{Aymax} (191 deg)
  - 2nd steer = 1.5*θ_{Aymax} (287 deg)
  - 3rd steer = 2.0*θ_{Aymax} (382 deg)



Miscellaneous Test Conditions

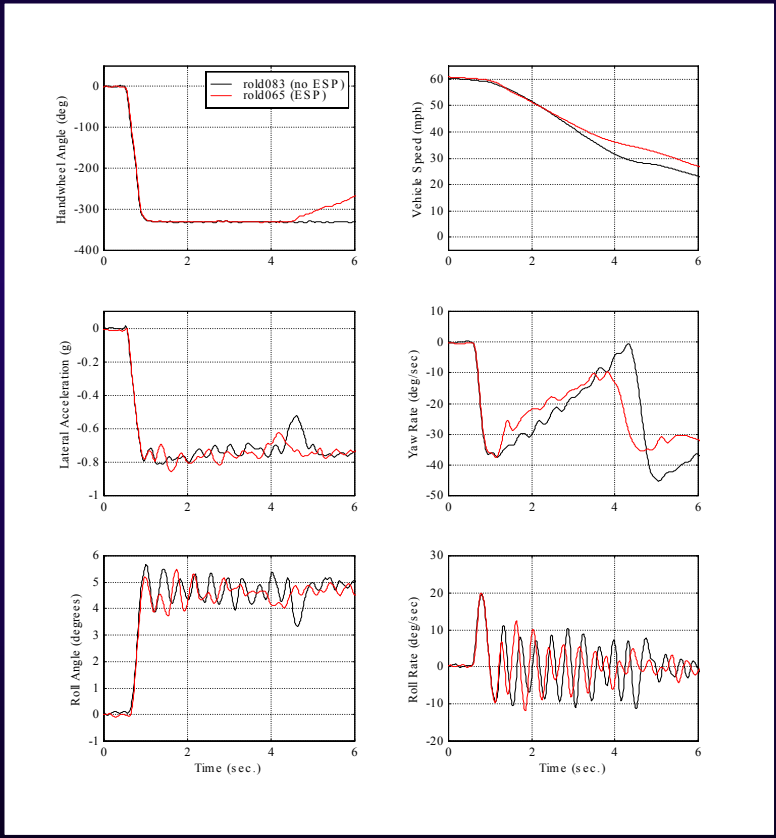
- Vehicle speed incrementally increased
- Performed with and without stability control
- Front and rear mounted outriggers
- Lightly laden
- Dry, high-mu asphalt surface
- Used the steering machine
- Performed with steering in both directions

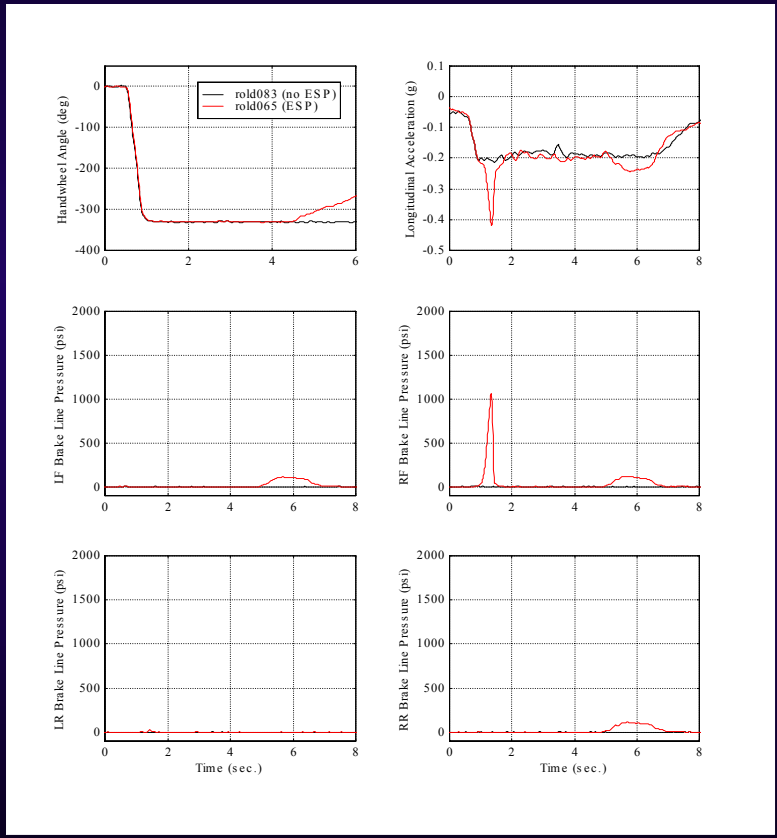
Preliminary Results (J-Turn)

Vehicle	Early Termination Condition			
	Right Steer		Left Steer	
	Stability Control	Disabled Stability Control	Stability Control	Disabled Stability Control
ML320	--	N/A*	--	--
LX470	--	Plow-out (55.0 mph)	--	Plow-out (54.4 mph)

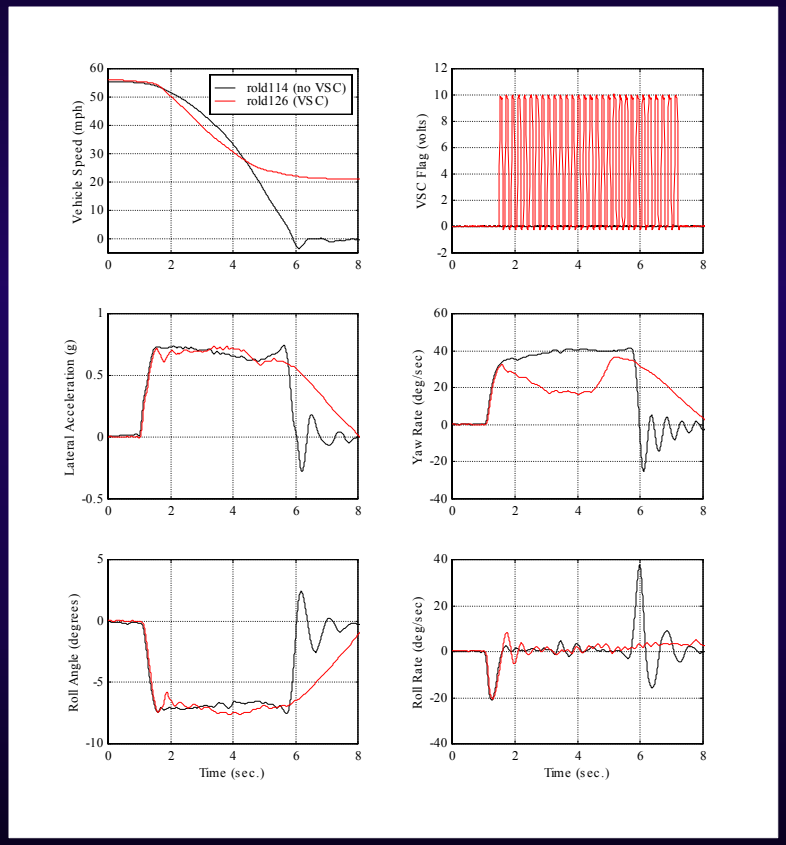
*Test not required. No ESP intervention was detected during active-ESP, right-steer J-Turn testing.

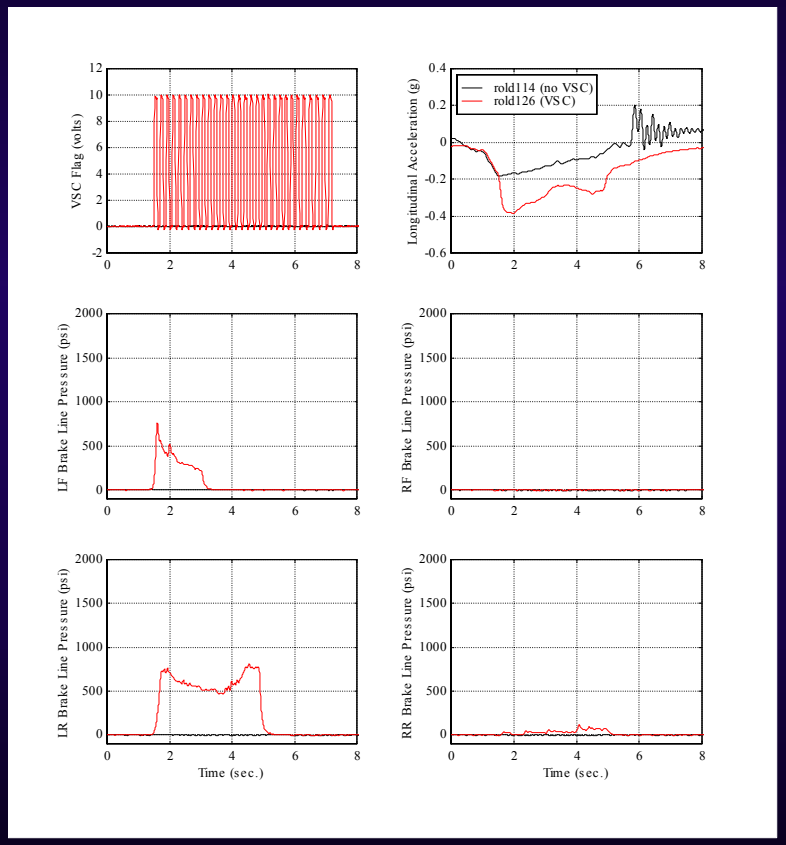
J-Turn Results – ML320





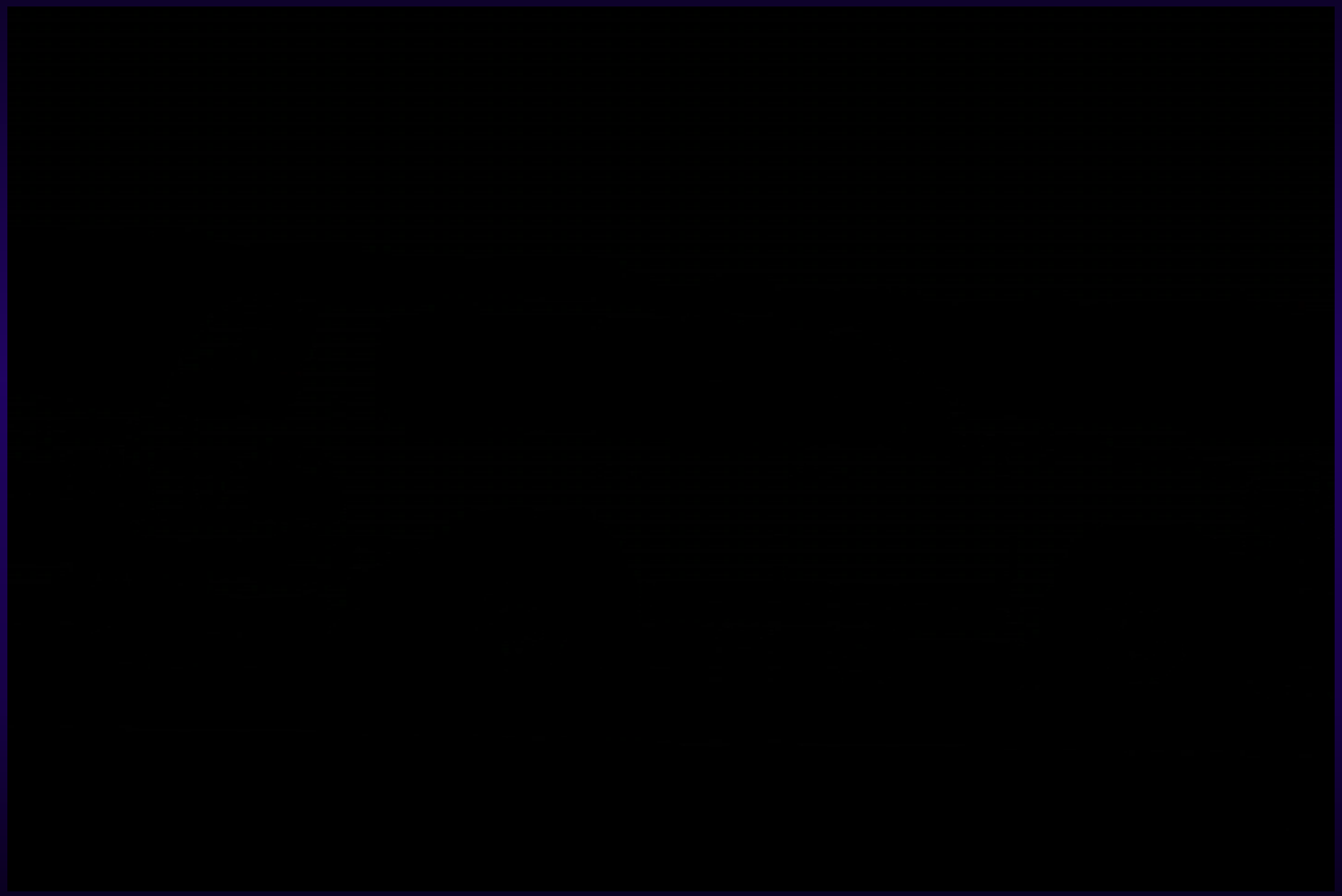
J-Turn Results – LX470





J-Turn Video

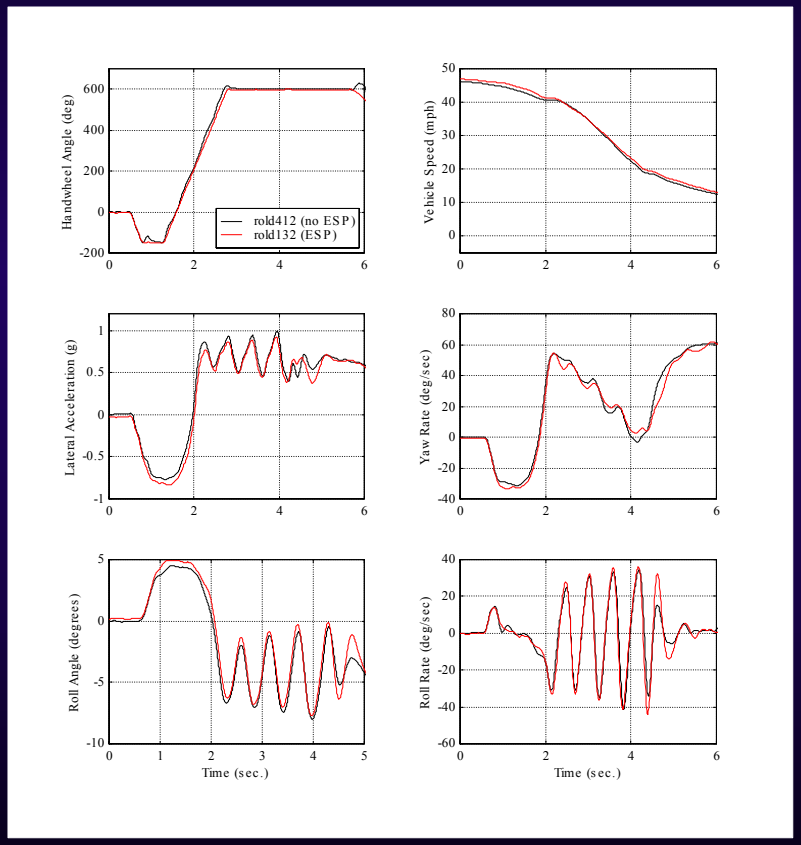
- LX470
- w/o VSC at 55.0 mph (plow-out)
- w/VSC
  - At 55.5 mph
  - At 60.0 mph

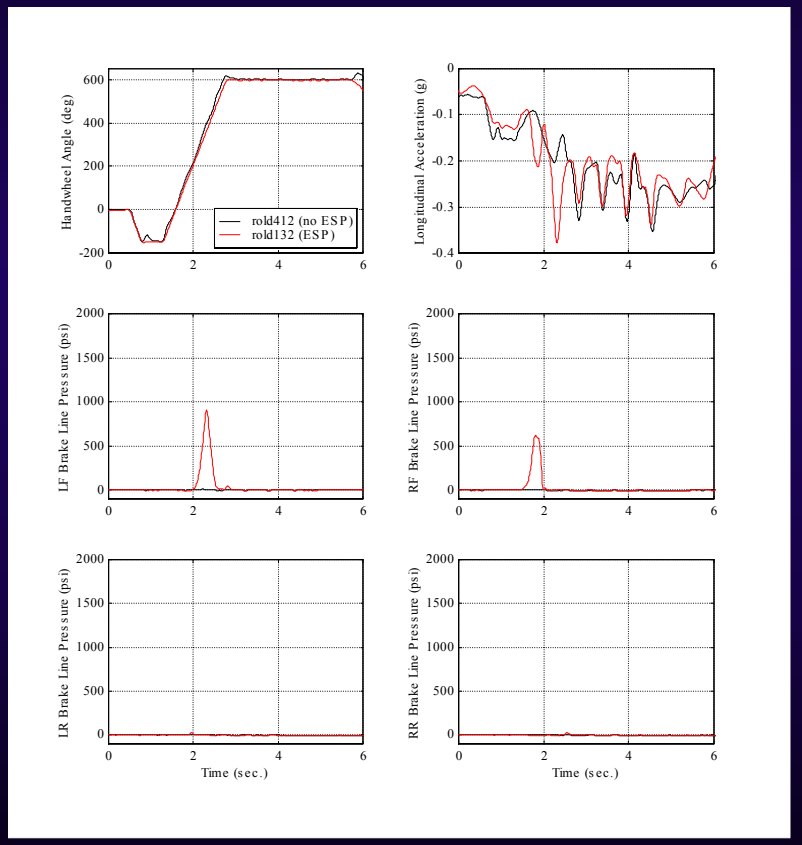


Preliminary Results (Fishhooks)

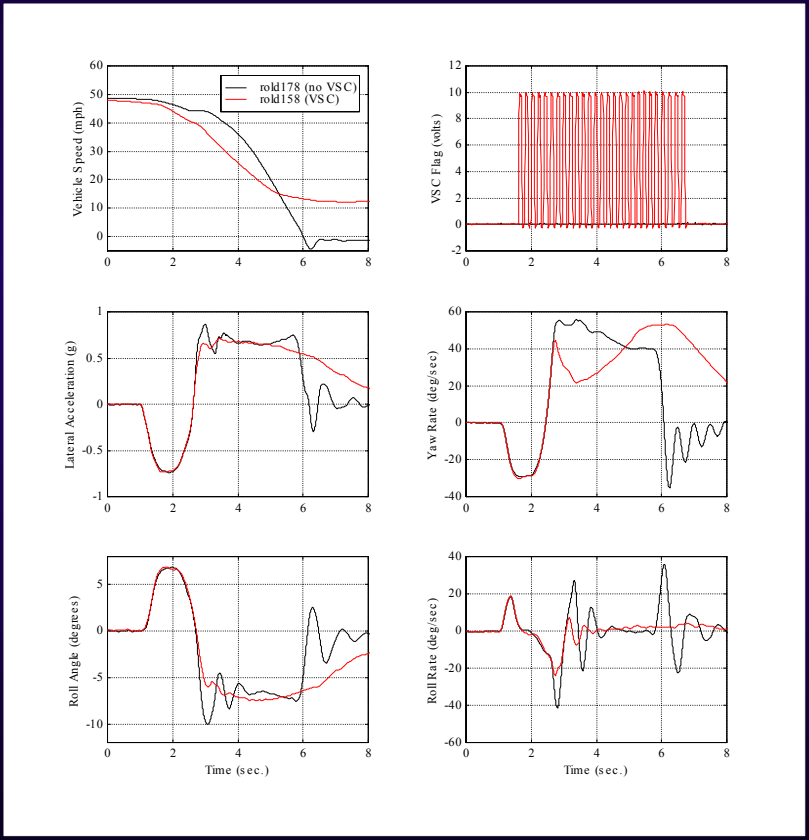
Vehicle	Fishhook Maneuver	Early Termination Condition			
		Right-Left		Left-Right	
		Stability Control	Disabled Stability Control	Stability Control	Disabled Stability Control
ML320	1	--	--	Minor TWL (38.8 mph)	Minor TWL (35.2 mph)
	2	Minor TWL (45.5 mph)	Minor TWL (47.0 mph)	Minor TWL (46.4 mph)	Minor TWL (44.0 mph)
LX470	1	--	--	--	Minor TWL (40.3 mph)
	2	--	--	--	Minor TWL (47.3 mph)

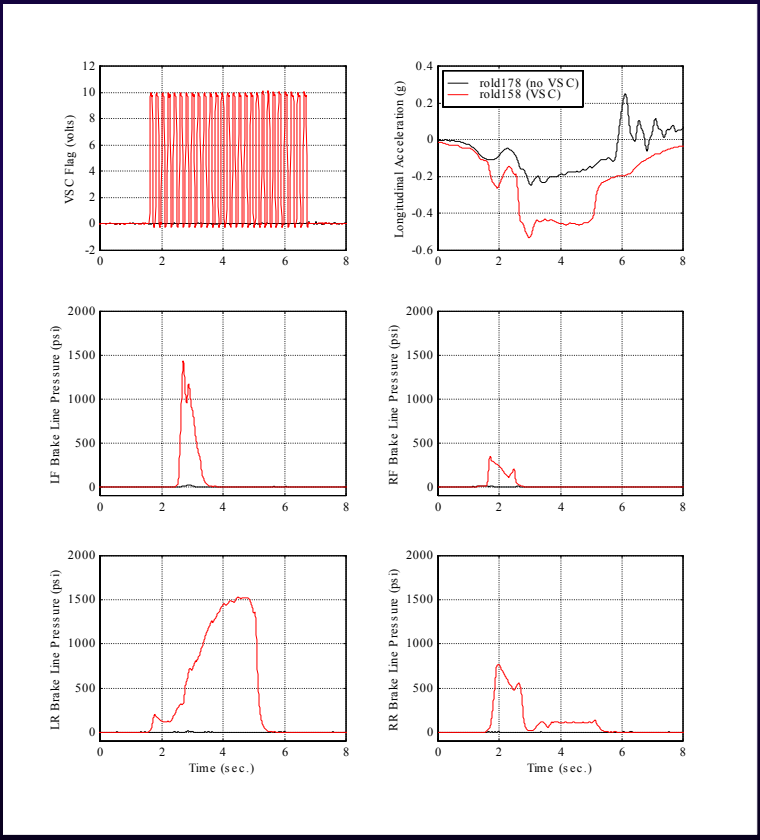
Fishhook #2 Results – ML320





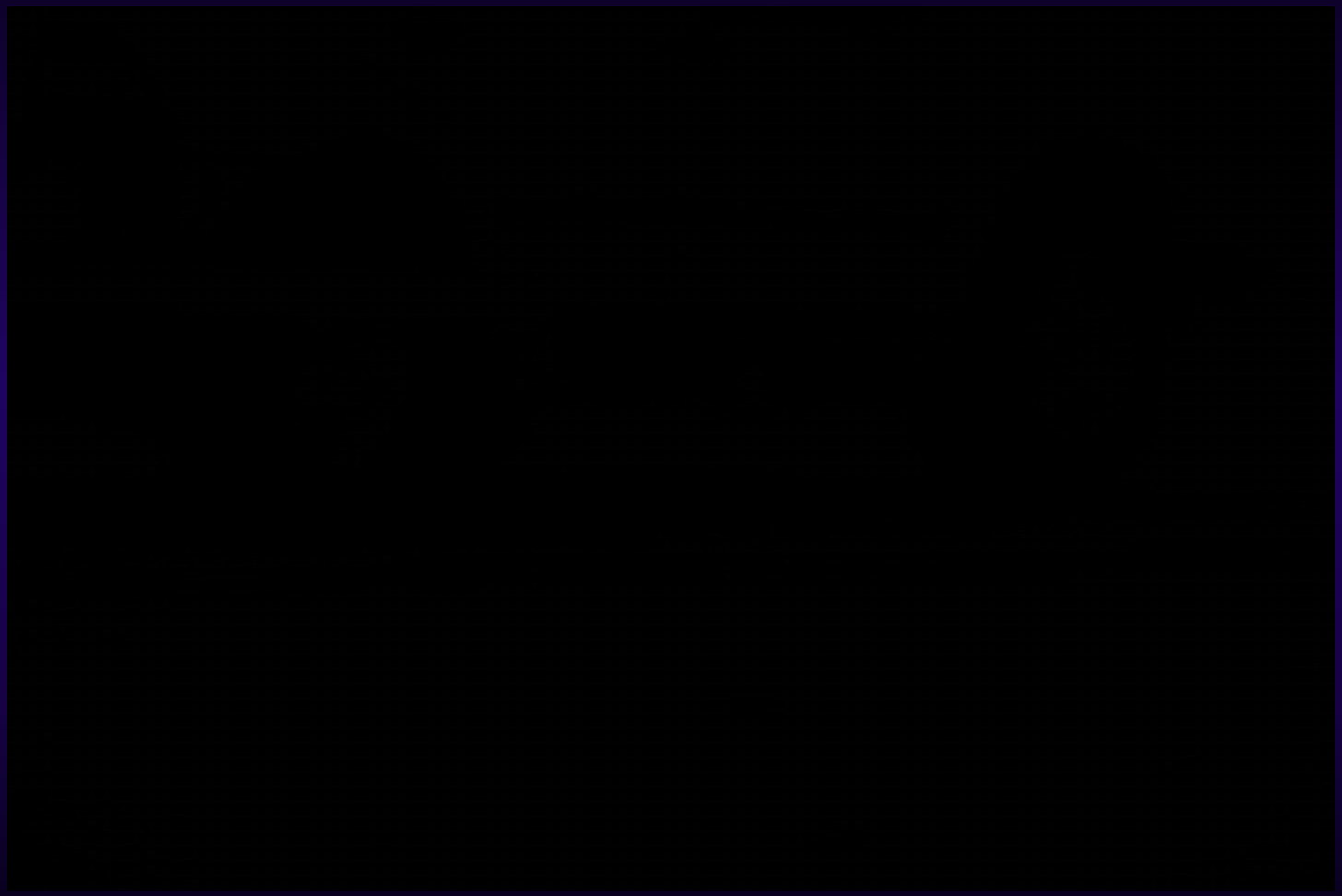
Fishhook #2 Results – LX470





Fishhook #2 Video

- ML320
- Minor TWL w/o ESP
  - 45.6 mph
  - Increasing roll oscillations
- Minor TWL w/ESP
  - 46.4 mph
  - Increasing roll oscillations



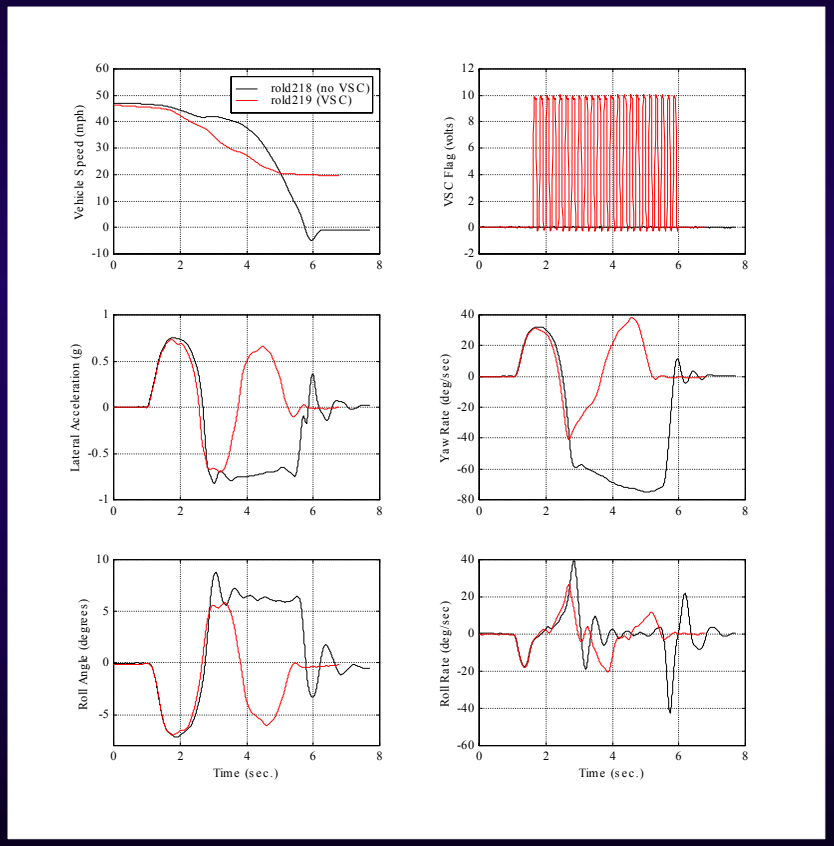
Preliminary Results (PRISM)

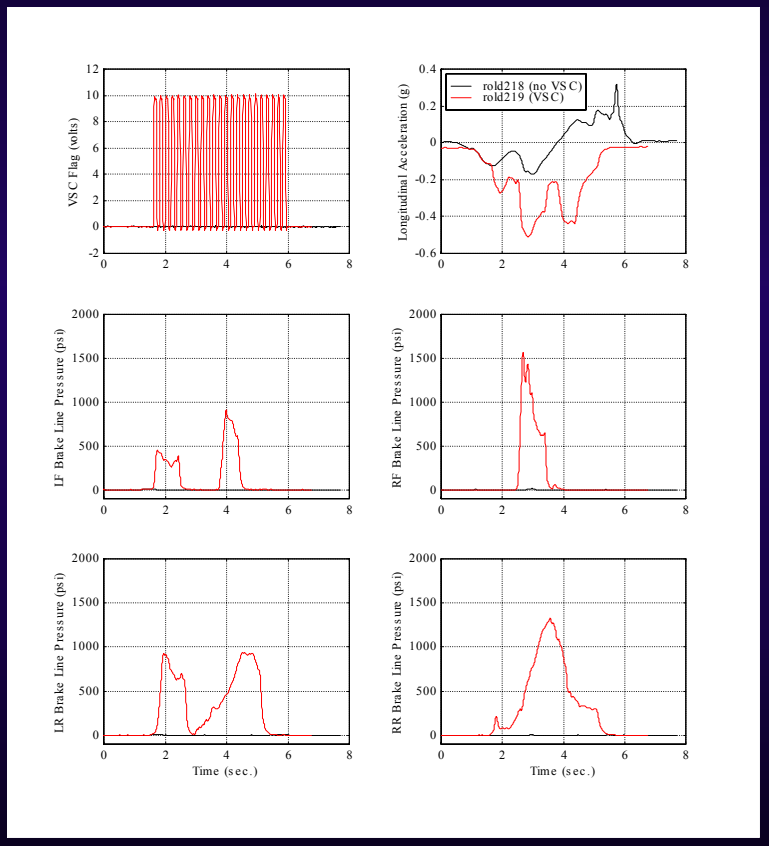
Vehicle	Early Termination Condition*			
	Right-Left-Right		Left-Right-Left Steer	
	Stability Control	Disabled Stability Control	Stability Control	Disabled Stability Control
LX470	Only 1 test (45.5 mph)	Spin-out** (46.7 mph)	Only 1 test (45.7 mph)	Spin-out and TWL (46.7 mph)

*Termination conditions not defined prior to PRISM testing. Spin-outs were observed during each non-VSC test performed above 40 mph.

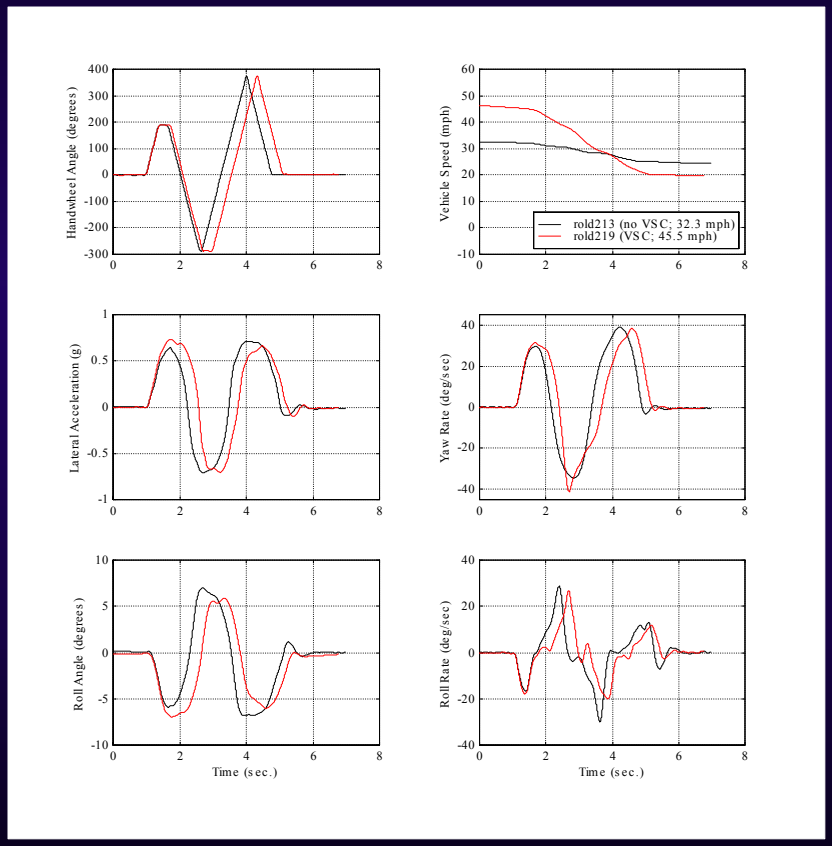
**Two-wheel lift observed earlier at 38.1 mph

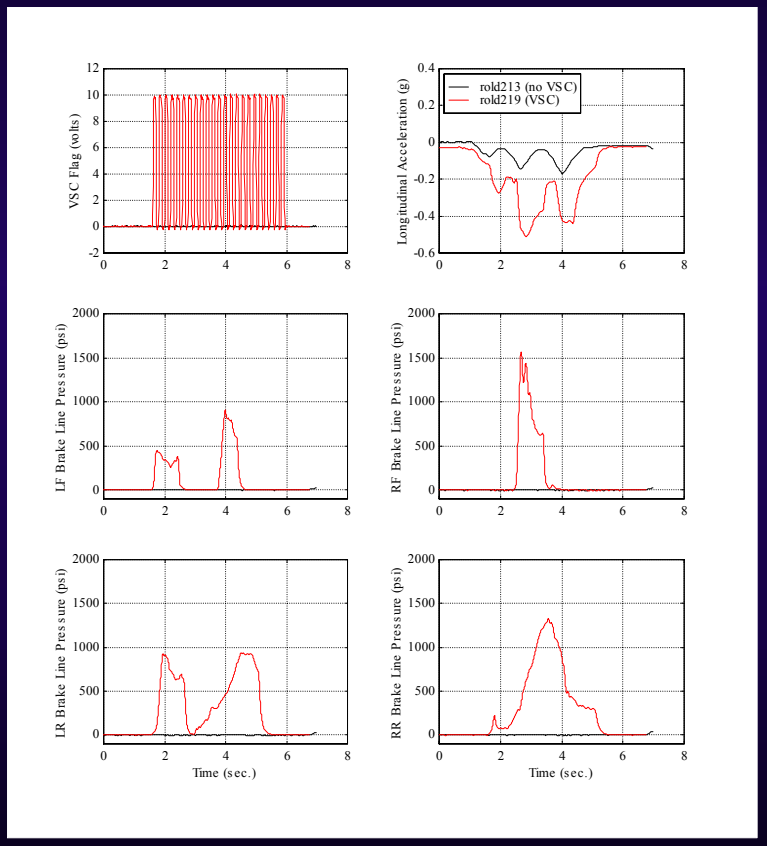
PRISM Results – LX470





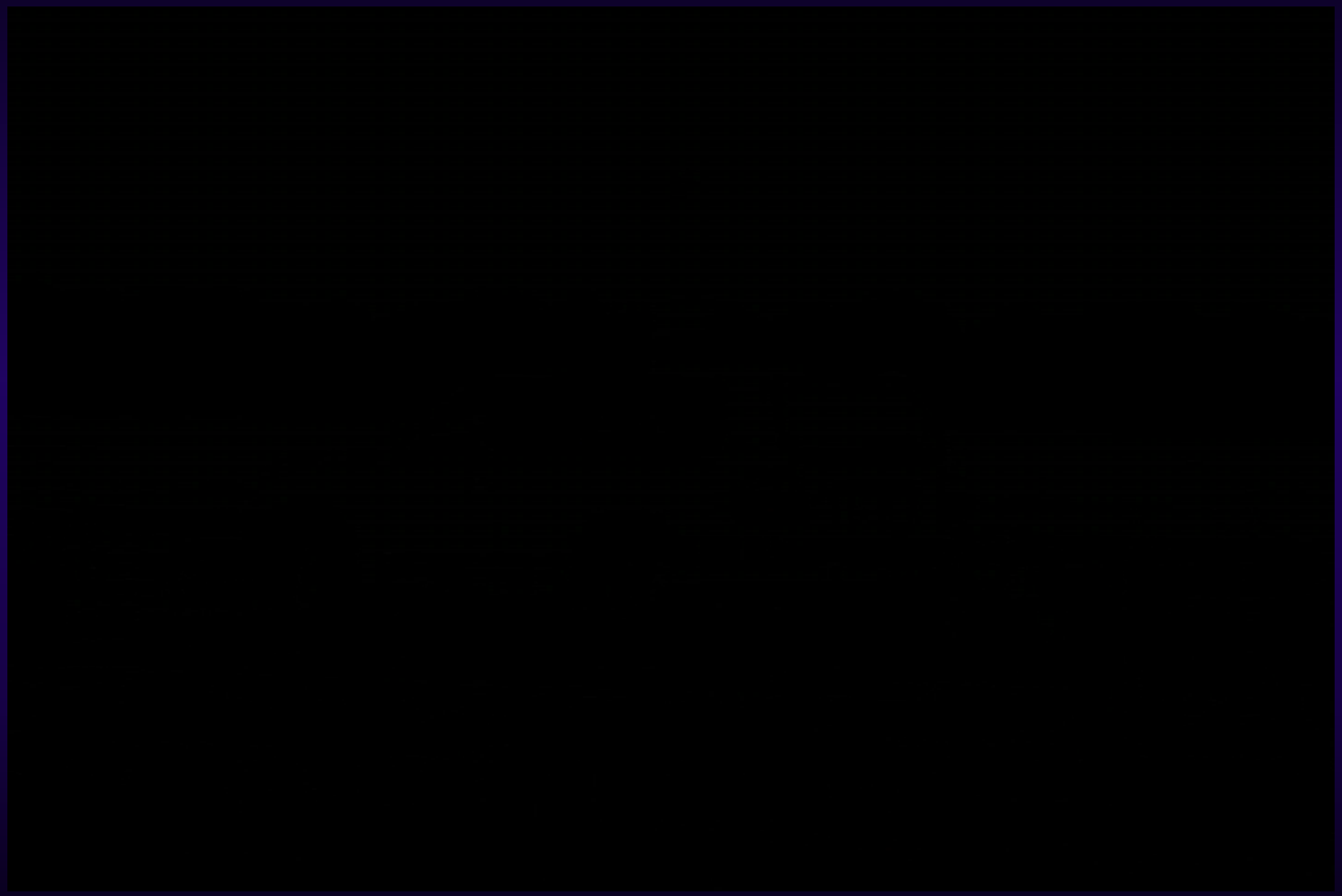
PRISM Results – LX470





PRISM Video

- LX470
- w/o VSC
  - 38.1 mph
  - Two instances of minor TWL at 38.1 mph
  - Spin-out, no TWL at 46.7 mph
- w/VSC
  - 45.5 mph
  - Similar speed to max used w/VSC



Future Testing

- 2 / 4 Vehicles purchased for TREAD Act maneuver development are equipped with stability control
  - 2001 Toyota 4Runner
  - 1999 Mercedes ML320
- TREAD-related maneuver development test matrices promise to be extensive
  - Optimized Fishhooks and J-Turns
  - Handling maneuvers (e.g., Elk Test, etc.)
  - Vehicle modifications
- Performed with and without stability control

Conclusions

- NHTSA has begun to research stability control
- TREAD Act related testing will allow NHTSA to gain significant experience with stability control and how it relates to dynamic rollover propensity
- Potentially promising technology
- Vehicle response with stability control can be very different than that with it disabled
- Customers should be educated about what stability control can and cannot do